"In the West Atlantic, and particularly between the Bermudas and the Azores, it was possible to trace all the charts with precision, thanks to the complementary information which we received. The mean number of observations received daily was more than 10. For some days, which coincided with the passing of a very strong tempest in the North Atlantic, we received an average of 20 simultaneous observations from ships. The record was reached on the 22d of Feburary at 1 p. m., with 30 simultaneous observations.

"In the East Atlantic, where the radio traffic is very intense, as usual, we received only one rather feeble mean of observations of ships, but thanks to the message received from the Eiffel Tower, and to our communications with the steamers of the line from New York, the tracing of the charts was not less precise. We retransmitted to the Office National Météorologique the observations of the steamship *France;* those of the *Lafayette*, bound to the southwest of Spain toward the Azores, and finally those of the steamship *Paris*, bound for New York. As soon as this ship lost direct contact with Brest, we took charge of the retransmission of the messages. Two appointments were made a day for this purpose, and the observations of the *Paris* were retransmitted to the Office National Météorologique with ours immediately afterwards.

"The Weather Bureau is disposed to maintain this service of retransmission by the "Angot" message; it wishes only when the *Jacques Cartier* is on the sea, to receive our observations, too. These will be added by the Office National Météorologique to the European messages of "Lyon-Annapolis." We are favorable to this idea, which would make the *Jacques Cartier* play a true rôle of "meteorological cruiser" and centralization station. There would also be a chance to authorize us to transmit clearly the positions of the centers of depression. information which would be exchanged between the two meteorological services via Annapolis-Lyon.

CONCLUSION.

"We believe we can affirm that from the point of view of receipt, as well as of transmissions and retransmissions, we have obtained in the course of the voyage of January and February, 1923, results which are incomparably superior to all preceding ones. Mr. Bowie showed great astonishment at the results obtained. He declared to us that he had never had an idea of the precision with which one could follow the evolution of meteorological phenomena and forecast their effects, while crossing the ocean. We believe that from the moment the United States has verified this success officially, the Office National Météorologique will leave no stone unturned to keep up the present organization of the *Jacques Cartier*, which on this voyage exceeded all hopes. We will close by citing the number of meteorological messages which were received by the two operators of the *Jacques Cartier*, and the number of telegrams of information, general or particular, which were sent. The first number is 500 messages received; the second, 140 messages sent. Finally, we will remark that the results obtained are largely due to the regularity of the radio service and the precision with which the messages are received. The two radiotelegraphers are at present giving us incomparable service, and the training of other operators for this work would seriously upset the enterprises by dissipating our energy for an undetermined period of time. We are therefore of the opinion that it is indispensable to grant to these officers a special indemnity in keeping with the services which they render to the Office National Météorologique and to Atlantic meteorology."

The single example of the weather information broadcast by the *Jacques Cartier* here given will convey an excellent idea of the scope of the meteorological activities of that vessel:

BROADCAST—MARCH 20TH—GREENWICH NOON.

Meteo. *Jacques Cartier* to all ships: North Atlantic weather situaiion March 20th, Greenwich noon.—Pressure is high over northwestern Europe 30.36; also from Bermuda to Azores and northward also over American Atlantic States. Trough of low pressure extending from Iceland (29.60) southeastward to Gibralter (29.50). Disturbance of great intensity (29.00) over Newfoundland moving east-northeastward.

Forecasts.—Track, Azores to Gibralter—unsettled weather eastern portion—northerly fresh winds, squally weather and overcast weather western portion. Stop. Tracks, Azores to English Channel—overcast weather and moderate easterly winds eastern portion—fresh or strong northerly winds and squally weather western portion. Stop Azores region—fresh northerly winds moderating to-day and shifting to southeast and south to-morrow—overcast weather becoming fair. Track, Azores to Bermuda—Moderating northerly winds and fair weather between longitudes 30° and 42°. Southerly increasing winds shifting to southwest west of 42; weather becoming overcast and probably rainy.

Advisory for westbound ships over transatlantic tracks west of Ireland to south of Grand Banks: Disturbance of great intensity (29.00) over Newfoundland moving toward Iceland will be attended by strong shifting winds to-day and to-night between longitudes 35° & 55° followed by fresh or strong northerly winds. Winds will shift to-morrow morning between 40° & 50°.

CONCERNING THE ACCURACY OF FREE-AIR PRESSURE MAPS.[1]

By C. LE ROY MEISINGER, Meteorologist.

[Weather Bureau, Washington, D. C., April 1, 1923.]

INTRODUCTION.

The necessity for knowing the accuracy of the charts.—The computation of barometric pressure at free-air levels is a purely mechanical operation after one has constructed the necessary tables; but the verification of the results of such computations is a much more difficult matter, since a rigidly accurate standard of comparison does not exist. It is true that free-air pressures and temperatures are measured by means of kites, and wind velocities by pilot balloons, but these measures are, for one reason or another, frequently not comparable with the results of computation.

Experience has demonstrated that maps depicting the barometric distributions at free-air levels are often considerably at variance with those representing sea-level conditions. If these differences are real, it is reasonable to suppose that they are physically significant, and one may hope to learn by study and experience what the significance is. On the other hand, if they are false, one may be seriously misled in attempting to interpret them. Therefore, if we are to have confidence in these charts, it is imperative that we ascertain, in every possible way, the degree of accuracy that may be expected of them. This is the purpose of the present inquiry.

The maps upon which the inquiry is based.—The maps examined in the preparation of this paper were constructed daily during the months of December, 1922, and January and February, 1923, from postcard reports mailed to the Central Office of the Weather Bureau at Washington, from 29 Weather Bureau stations in the central and eastern United States. Under the authority

[1] Presented before the American Meteorological Society, at Washington, D. C., Apr. 16, 1923.

of Weather Bureau *Circular*, dated November 20, 1922, these stations were supplied with the necessary reduction tables and instructions for reducing barometric pressure to the levels of 3,281 feet (1 kilometer) and 6,562 feet (2 kilometers) above sea-level.[2]

The method by means of which the reduction tables were constructed has been completely set forth in MONTHLY WEATHER REVIEW SUPPLEMENT No. 21,[3] and will not be discussed here.

The postcard reporting was discontinued at the end of February in order that time might be afforded for a complete and careful study of the results. It was believed that if these months—the season of the weather's most annoying caprices—should yield results of value, even brighter should be the prospects during less active seasons.

COMPARISONS OF OBSERVED AND COMPUTED PRESSURES.

The problem of obtaining comparable data.—In seeking to arrive at an estimate of the accuracy of the results of computation, one of the most obvious methods is to compare the computed pressure (based upon surface observations) with that reduced from the record of the kite meteorograph. At first sight, this seems a direct and simple comparison, but, in truth, it is neither direct nor simple; for, between the vibrant pen of the meteorograph, tracing its record among the clouds, and the columns of cold figures whence the residuals are derived, is a tedious series of computations, interpolations, and extrapolations. This is no fault of the methods of aerological reduction, for these complexities arise naturally through the character of the recorded data and in the reduction of the kite observation to the epoch of the computation. The chief difficulty lies in knowing the magnitude of the effect of pressure and temperature variations between the time of computation and the time when the kite attained the level in question.

However, the values of barometric pressure corresponding to 8 a. m., 75th meridian time, have been prepared with scrupulous care by members of the Aerological Division of the Weather Bureau and subjected not infrequently to review and check.

Frequency distributions of residuals.—During the three months, there was made at the six aerological stations of the Weather Bureau, a total of 251 kite flights yielding pressure values for the two selected levels suitable for comparison with computation. After rendering these values as nearly as possible representative of 8 a. m. (75th meridian time) conditions, they were compared with the computed values, and the difference was regarded as negative in sign when the computed pressure was less than the observed, and positive when the computed pressure was greater. Classifying these residuals by hundredths of an inch, frequency distributions have been obtained. Figure 1 contains curves of the frequencies of errors of the several magnitudes for the two levels separately and combined, using data from all the stations. The principal features of these curves are:

(1) For the 3281-foot level, there are no errors in excess of 0.1 inch. The mode of the curve is at the zero class, but the curve is slightly asymmetrical, showing a larger number of negative residuals than positive.

(2) For the 6,562-foot level, the range of error is somewhat less than twice that of the lower level. This is to be expected from the nature of the hypsometric equation, in which the length of the reduction column is an important term. Other conditions being equal, a given error in the mean temperature of the air column will produce, in the United States east of the 100th meridian where the longer air column is nearly twice that of the shorter, an error in pressure at the upper level nearly twice the magnitude of that at the lower level.

The curve is nearly symmetrical, but has its mode in the -0.03 class. From this it would appear that, during the period of the observations, the temperature arguments should have been, in general, somewhat higher. This would not decrease the number of large residuals but would simply shift the curve to the right. A large number of these negative residuals was contributed by the comparisons of data from Due West, S. C. This station has been established since the method for computing was devised and, as a consequence, none of its data has contributed to the original investigation. The comparisons for Due West are, therefore, on a somewhat different footing, as will be explained later.

(3) When the residuals for the two levels are combined, the curve has its mode practically in the zero class but is somewhat skew, with an excess of negative values. This curve, which is simply the sum of the two mentioned above, derives its characteristics very obviously from the features of its components.

Individual station histograms.—Since it appears that more is to be learned through dividing the data into groups than by studying them *en masse*, it is desirable to subdivide the curves of figure 1 into separate station groups. When thus subdivided, the number of observations becomes too small to subject to statistical investigation. Indeed, it has been deemed advisable to present in the station histograms only the combined residuals from both levels. These histograms are given in figure 2.

In spite of the paucity of data, there is a certain obvious geographical influence operative in the distribution of residuals in the several diagrams. Stations in lower latitudes show extremes larger on the negative side than do the northern stations. Drexel, Nebr., with its large number of observations, shows an almost symmetrical distribution; Ellendale, N. Dak., shows the largest positive residuals; and Groesbeck, Tex., the most southerly of the stations, the largest negative errors. Owing to the unique characteristics of Due West, S. C., explained above, we may, for the moment, disregard its histogram.

Why should the southern stations yield a larger number of negative residuals than the northern? It is true that in the original study, the number of available kite observations which could be utilized for formulating the reduction method was greatest from Drexel and Ellendale; but, if the negative tendency at Groesbeck, for instance, were the result of nothing other than poor estimates of the mean temperature of the air column, one should expect that the distribution of errors, however wide, should follow the Gaussian law. The cause seems to lie rather in the geographical and seasonal characteristics of temperature at the particular stations.

[2] Another regrettable example of the confusion arising from the use of two systems of units is found here. The original papers, in which the method of making these free-air maps was described, employed metric units exclusively, because the aerological data, which were fundamental to the study, were thus tabulated. When it became necessary to make the application of the method at the regular stations of the Weather Bureau, it was desirable to render the maps in English units, both because of the familiarity of the observers with these units, and because of the necessity of having the maps readily comparable with the sea-level map. Consequently, in this paper, it has been decided to use the English units primarily, giving the metric equivalents in parentheses.

[3] Meisinger, C. Le Roy: *The preparation and significance of free-air pressure maps for the central and eastern United States.* Washington, 1922. An extended abstract of this SUPPLEMENT appears under the same title in MO. WEATHER REV., Sept., 1922, 50: 453-468.

Since negative errors in the mean temperature of the air column are productive of negative errors in reduced pressure, it appears that the southern stations must possess characteristics that will produce such negative errors occasionally and more frequently than northern stations. Such errors may result from: (1) An underestimation of the difference between the surface temperature and the mean temperature of the air column; or, (2) a *surface temperature that is abnormally low owing* to radiation conditions; local conditions, such as exposure of thermometers; or *thermal peculiarities associated with particular wind directions.*

For instance, consider Groesbeck (which yielded the largest number of large negative residuals) in the light of the surface wind direction current at the time of the reduction. Of the 17 cases of residuals at the 6,562-foot (2 kilometer) level of −0.1 inch or greater, 6 occurred with southwest winds, 5 with south winds, one each with the other winds, except west, and one with a calm. The largest residual, −0.18 inch, occurred with a southwest surface wind. An investigation of the vertical temperature gradient as observed at Groesbeck by kites on the morning of January 10, 1923, the date of this large discrepancy, reveals an inversion of extraordinary magnitude. The barometric situation at the surface showed high pressure to the south of the station. The weather was clear and the surface winds light. At the inversion level, the wind was west-southwest and of *greater speed. Surface temperature measured simultaneously* at Palestine, Tex., the nearest station reporting daily to Washington, was 46° F., as compared with 38° F. at Groesbeck. The exposure of thermometers at Groesbeck is 11 feet above the ground, while at Palestine these instruments are on a roof 64 feet above ground. These temperatures indicate, therefore, that the low pressure computed for the upper level was not so much the result

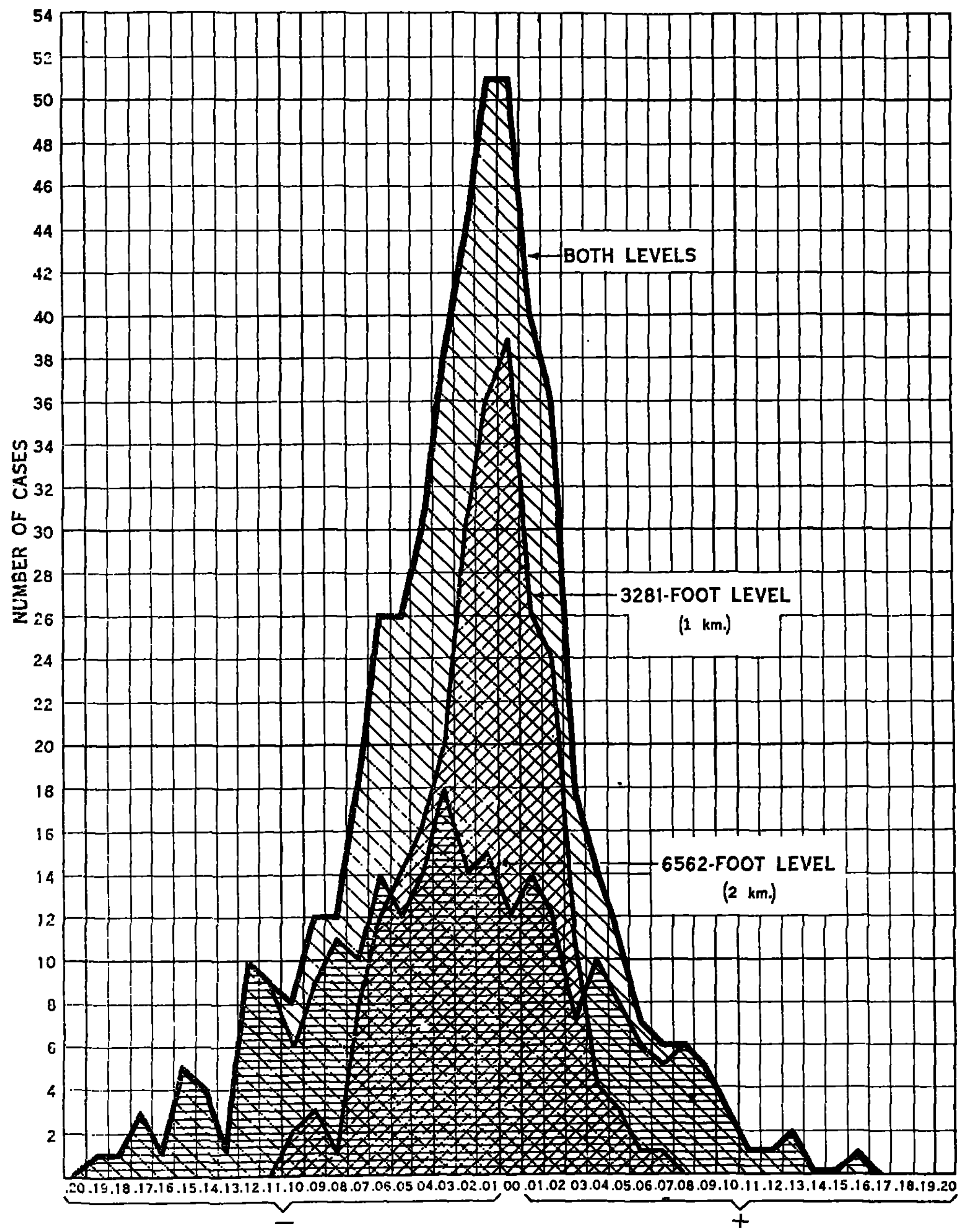

FIG. 1.—Frequency distributions of differences between observed and computed free-air pressures for the 3,281-foot level and 6,562-foot level, and for both levels combined. Data obtained from the six aerological stations of the Weather Bureau during the winter months of 1922–23.

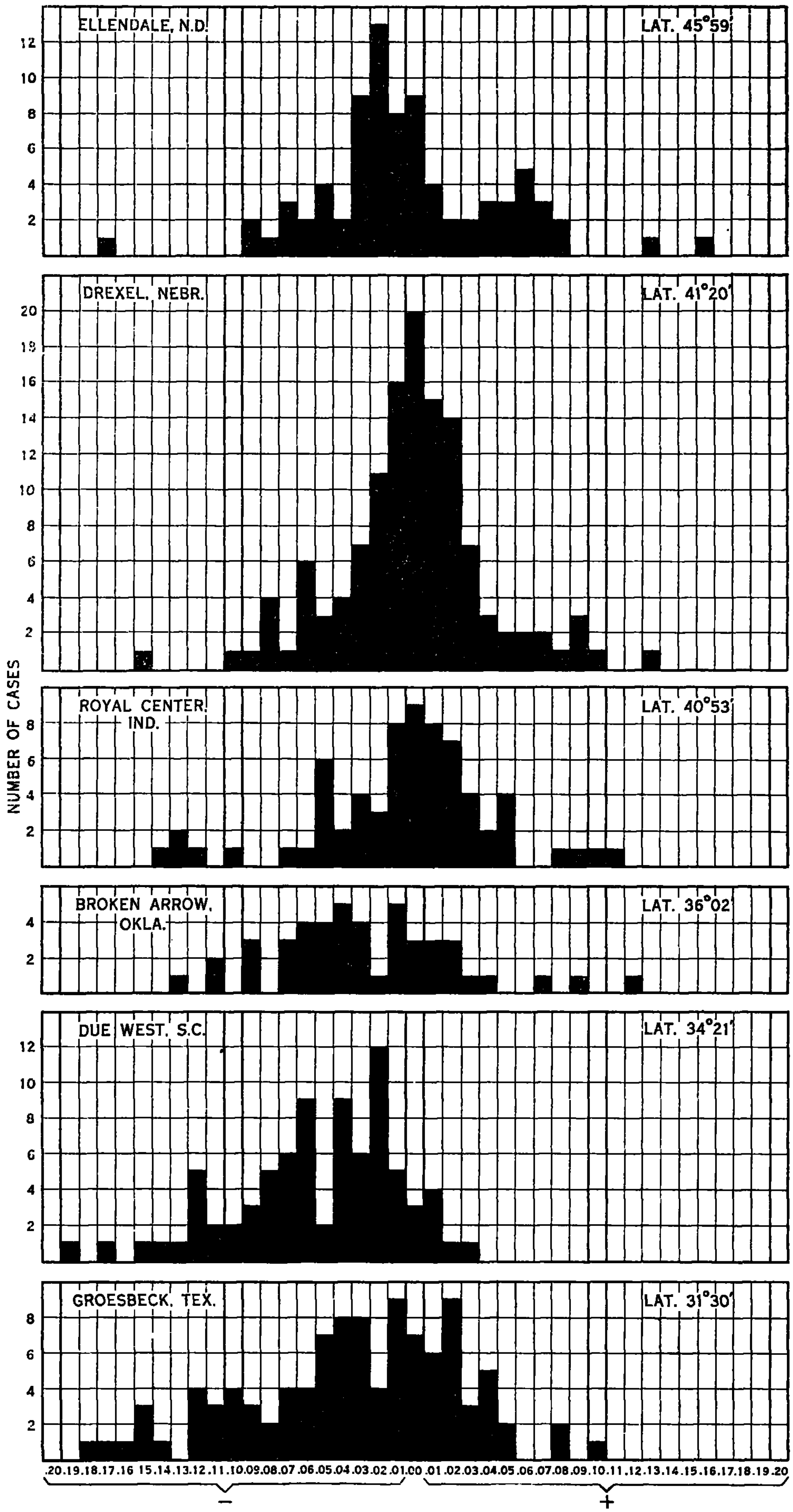

FIG. 2.—Frequency histograms for the six aerological stations of the Weather Bureau, showing the number of cases of differences of different magnitudes between observed and computed free-air pressures; both levels combined.

of warm air introduced at and above the inversion level as of an unusual cooling at the surface, probably through nocturnal radiation. The full effect of this radiational cooling was registered by thermometers so near the surface.

In Table 1 have been classified the data similar to those given above for each of the 17 cases of large discrepancies at Groesbeck.

TABLE 1.—*Temperature and wind conditions at Groesbeck, Tex., upon the occasions of the 17 largest negative errors of computation.*

Date.	Error.	Mean temperature of air column. Observed.	Computed.	Difference.	Surface wind. Direction.	Velocity.	Difference between Palestine and Groesbeck.[1]
1922.	*Inches.*	°*F.*	°*F.*	°*F.*		*M. p. h.*	°*F.*
December 15	−0.15	47	37	−10	n.	22	+3
20	−0.15	44	31	−13	e.	5	+5
22	−0.14	50	38	−12	sw.	7	+7
25	−0.16	56	42	−14	s.	3	+8
29	−0.15	54	41	−13	s.	8	+9
1923.							
January 4	−0.10	50	42	−8	sw.	12	+1
6	−0.12	51	39	−12	ne.	7	+3
7	−0.12	60	50	−10	sw.	12	+3
8	−0.17	55	43	−12	calm.	....	+7
10	−0.18	55	38	−17	sw.	11	+8
11	−0.11	61	51	−10	sw.	16	+1
17	−0.10	51	42	−9	s.	7	+4
24	−0.12	47	37	−10	s.	10	−2
25	−0.11	54	45	−9	se.	7	+3
February 17	−0.11	37	28	−9	nw.	9	+1
19	−0.10	44	35	−9	s.	8	+3
20	−0.12	50	40	−10	sw.	3	+5

[1] Positive sign (+) indicates higher temperature at Palestine than at Groesbeck.

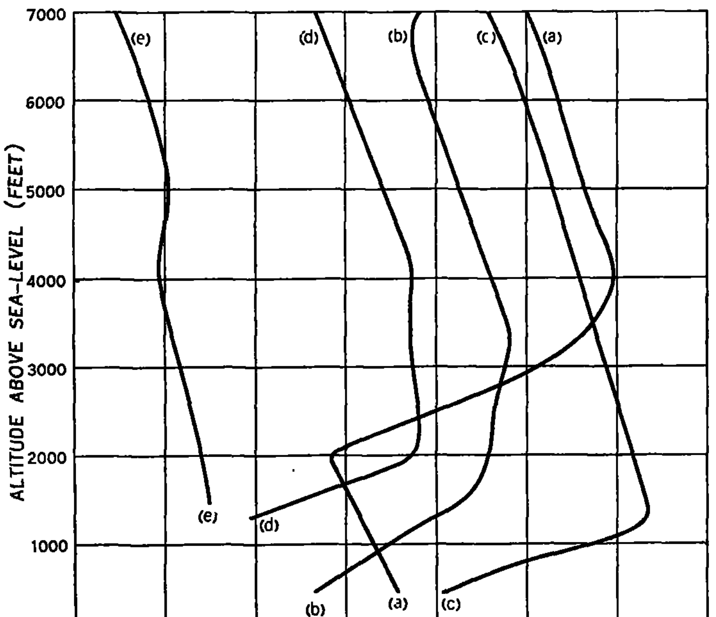

FIG. 3.—Specimens of vertical temperature curves determined by means of kites at several of the aerological stations. (*a*) Groesbeck, Tex., December 15, 1922; pressure error at upper level, −0.15 inch; surface wind, north. (*b*) Groesbeck, Tex., December 20, 1922; pressure error at upper level, −0.15 inch; surface wind, southeast. (*c*) Groesbeck, Tex., December 25, 1922; pressure error at upper level, −0.16 inch; surface wind, east-southeast. (*d*) Drexel, Nebr., January 20, 1923; pressure error at upper level, −0.15 inch; surface wind, west-northwest. (*e*) Ellendale, N. Dak., January 20, 1923; pressure error at upper level, +0.13 inch; surface wind, northwest.

Figure 3 (a), (b), and (c), shows a group of vertical temperature curves as determined at Groesbeck on the ascent of the kite, selected from among the dates in Table 1. These show clearly the marked nature of the temperature inversions which were responsible for the large pressure residuals. Southerly stations, such as Groesbeck, do not show, on the average, a marked tendency toward inversions of temperature. When such exceptional cases do occur, it is clear that abnormally large errors will be produced in the computed pressure aloft.

At northern stations, such as Ellendale, in winter, the inversion is a relatively constant condition in the morning hours, and the method employed in reducing pressure allows for this more adequately as a consequence. At this station, for example, there were only three cases of errors greater than 0.1 inch, two of which were positive and one negative. The two positive cases indicate that a greater inversion was allowed for than actually

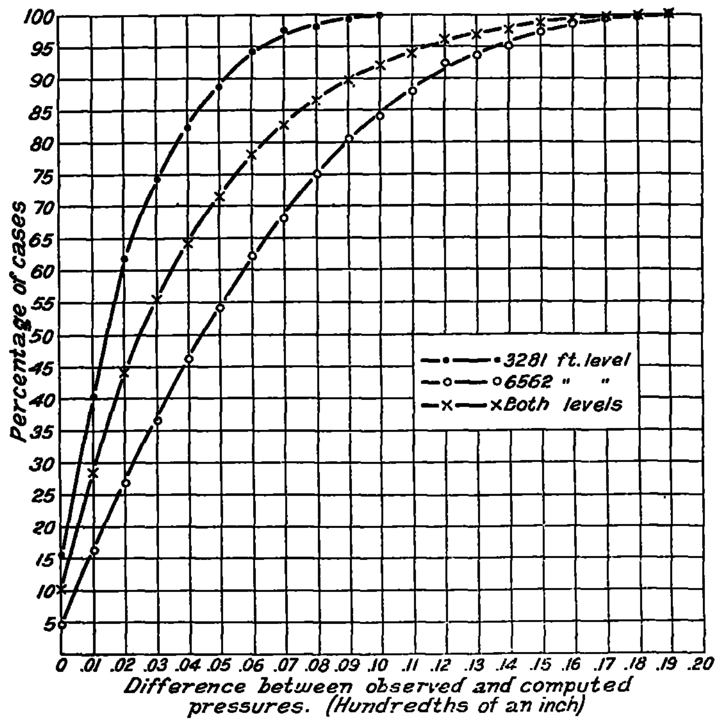

FIG. 4.—Curves for the two levels separately and combined, showing the percentage of errors of computed pressure of given magnitudes or smaller.

occurred. (See fig. 3 (e).) One case of a marked inversion at Drexel is shown in figure 3 (d). Drexel's large number of observations and symmetrical distribution of residuals, as well as its geographical situation, serve to produce the most satisfactory of all the histograms. Broken Arrow and Royal Center afford too few comparisons to justify reliable conclusions.

The outstanding feature of the Due West histogram is its tendency for negative residuals throughout. (Fig. 2.) It yielded the largest negative departure of any station, and the smallest number of positive departures. The curve is decidedly skew, and is also markedly displaced from symmetry with the zero class. The skewness may be attributed to the same causes as at Groesbeck and other stations, but the modal displacement to the left is probably the result of faulty geographical interpolation in one of the steps in the original research. The data for the eastern part of the United States were derived in the original papers from the stations at Mount Weather, Va. (near Washington, D. C.), and Leesburg, Ga. The record at the Virginia station was probably adequate for the purpose, but the length of the period upon which the Leesburg values were based was quite short. Due West, S. C., occupies a position approximately halfway between the two mentioned above. If, on the average, the temperature values had been enough higher to shift the histogram several classes to the right, this station would have stood out as one of the best. One hestitates, however, to recommend that the values for this station be increased upon the basis of these three months' experience. It is wiser to withhold judgment upon the best solution of the problem until other evidence has been presented.

Thus far considerable attention has been devoted to the large residuals. But sight should not be lost of the large number of very satisfactory and accurate calculations. Figure 4 shows for the two levels separately and, in a third curve, combined, the percentage of residuals of any given value or smaller. The curves take no account of the sign of the residual. For example, reference to the curve for the 3,281-foot level shows that about 89 per cent of all the computations were within 0.05 inch of the observed value; for the higher level the percentage is about 54, and for the two levels combined it is about 72. When it is recalled that the isobars on the daily weather map are drawn for intervals of 0.1 inch and that, in telegraphing pressures, only the even hundredths are coded, errors of 0.05 inch will exercise but little effect upon the map. The first two curves are based on 251 values each, while the last is upon the combined number, or 502.

COMPARISONS OF OBSERVED AND ESTIMATED WINDS.

The difficulties of obtaining reliable standards of comparison from pilot-balloon data.—It has been pointed out that some clue as to the reliability of the free-air maps may be adduced from the comparison of estimated wind directions, based upon the gradient wind relations, with winds actually observed by means of pilot balloons. Here, as in the case of kite data, the comparison is not direct, and, moreover, there are several sources of disagreement that are quite impossible of elimination and yet which may apparently, but not really, throw discredit upon the usefulness of the maps for purposes of estimating the wind direction.

In the first place, the theory of the gradient wind states that the wind direction, except so far as it is influenced by friction or viscosity, is perpendicular to the gradient at the level in question. A synoptic chart gives an instantaneous picture of the pressure distribution but gives no clue as to the true horizontal trajectory of an air particle unless the whole barometric formation is stationary—a condition which seldom occurs in nature. Nevertheless, the agreement between the direction of the observed wind at a given level and the trend of the isobars at the same level is usually sufficiently close to permit of a satisfactory determination of the general drift of the air.

Thus, in these comparisons, the estimate of wind direction was based entirely on the above-mentioned assumptions, and it is to be supposed, therefore, that, in the case of rapidly moving formations or those in which the intensity was changing rapidly, many discrepancies between observed and estimated winds must occur.

In addition to the complexities introduced into the comparison by the gradient wind assumptions, there is the further question as to the degree to which the pilot-balloon observations themselves are representative of the air drift at a given level. It should be remembered that pilot-balloon flights give but momentary indications for each level, since the balloon is constantly ascending. Moreover, under variable or rapidly changing conditions, two ascents separated by a short time interval may reveal winds varying in direction by several points at the same level. In general, this is true especially in the case of light winds, and on a warm summer day all manner of vagaries, real and apparent, may be introduced into the horizontal trajectory of the balloon by convective forces. Again, difficulties may be encountered in attempting to read from the altitude-direction curve the direction corresponding to certain arbitrary levels, such as those chosen for reduction purposes. The winds may have been turning rapidly just at the level in question, so that a small difference in elevation would show a quite different wind direction. Figure 5 shows a series of altitude-speed and altitude-direction curves in which this is clearly brought out.

It has been necessary to make estimates for station lying on the western frontier of the computations, an these estimates were probably in greater error tha

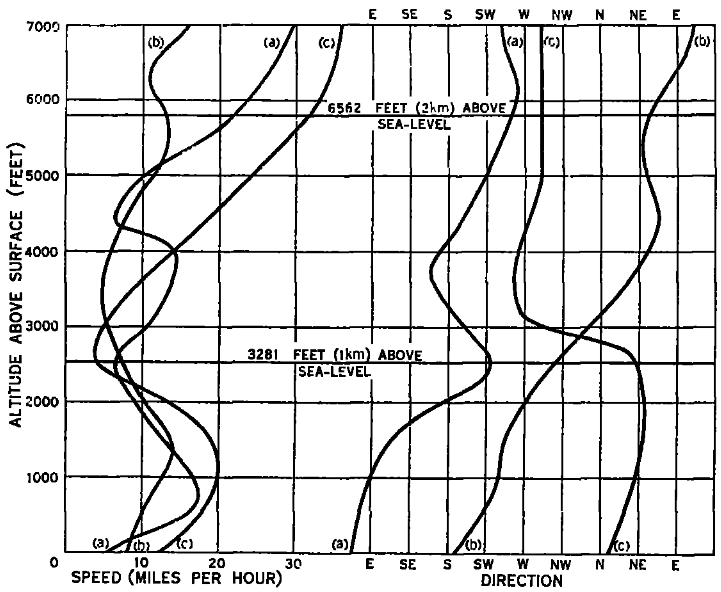

FIG. 5.—Altitude-velocity and altitude-direction curves for observations made by pilot balloons at Broken Arrow, Okla., showing examples of rapid turning of wind direction at certain levels, and the difficulty of determining at such elevations the true drift of the wind.

stations lying within the network, since the proper westward extension of the isobars was uncertain.

These factors all tend toward confusion in the determination of an absolute standard of accuracy in wind direction.

How the estimates were made.—The method used in arriving at the errors of estimation of free-air wind direction was as follows:

(1) Having completed maps for the two levels for a given date, a form, carrying as its first column a list of pilot-balloon stations of the Weather Bureau, the Army, and the Navy, was entered with the estimated direction of the wind for each station and level. This, it will be noted, was done in every case before actual observational material had yet been received, and was, therefore, entirely free from bias or influence which might unconciously arise if observed direction arrows had been plotted before the estimate was made.

(2) Upon completing this table for the period of a month, it was handed to the balloon section of the Aerological Division, where there were entered, for all stations at which observations were made at the required time of day, the direction recorded upon the observational form. All directions, both estimated and observed, were given on the 16-point scale. The observed wind speed was also entered.

(3) The classification of the errors of estimation was then made in the following manner: Facing the direction of the observed wind, the number of points on the 16-point scale, either to right or left, between this direction and that estimated was determined. For example, suppose a west wind was observed and a northwest wind was estimated: Facing the west, the northwest wind would be two points to the right in error. The observed velocity was also recorded in a class corresponding to a 2-point error to the right. Thus was formed a frequency table of 16 classes corresponding to the number of points of difference between the observed and estimated wind. The velocities also were tabulated in this way so as to make class averages possible.

What constitutes a correct estimate?—One is next faced with the problem of determining what shall constitute satisfactory agreement between the two. Owing to the difficulty of determining in many cases what the observed wind direction really was, it has been unanimously agreed among those with whom this matter was discussed *to define as correct an estimate that fell one point either side of the observed wind on the 16-point scale.* Successively, to either side of this class, the errors were designated as 1-point, 2-point, etc., on the same scale. In this way, the two classes of 7-point error coincide and represent the maximum possible error of estimation.

Error frequencies in wind direction.—In the lower part of figure 6 are shown two curves, one corresponding to the higher and one to the lower level. These curves show the percentage of errors falling within different classes, as defined above. The relatively high maxima of these curves as well as the sharp decrease of ordinates on either side of the correct class show at once the high degree of accuracy of estimation.

Errors in wind direction are not serious unless the velocity of the wind is high. Wind directions in nearly calm conditions have no significance. Therefore, in considering errors in estimating direction, one must also have regard to the corresponding velocity. In the two curves at the top of figure 6 there is shown for the two levels the average velocity of the wind, in miles per hour, corresponding to the several classes of errors. Owing to the very small number of large errors, it is apparent at once that the mean velocities at the extremes of the diagram would hardly be comparable with those at the center. Hence, the velocity curves were discontinued at class 4, although the points were plotted. *It is clearly seen that greatest accuracy is associated with highest velocity of the wind.* In these cases the wind velocity was about 30 miles per hour for the correct class, falling off to about 15 miles per hour at the points of discontinuance of the curves.

The two curves passing through the center of the diagram give the values of the square root of the number of observations upon which the means of the velocity are based. Since this quantity gives a measure of the relative value of the means, it is seen that the more accurate estimates are associated with more reliable mean velocities. Indeed, the ordinates of the curves at the extremes are less than 1/25 those in the center. It is reasonable to suppose that if enough large errors of estimation were available to give reliable means of velocity, those means would fall very low near the ends of the diagram.

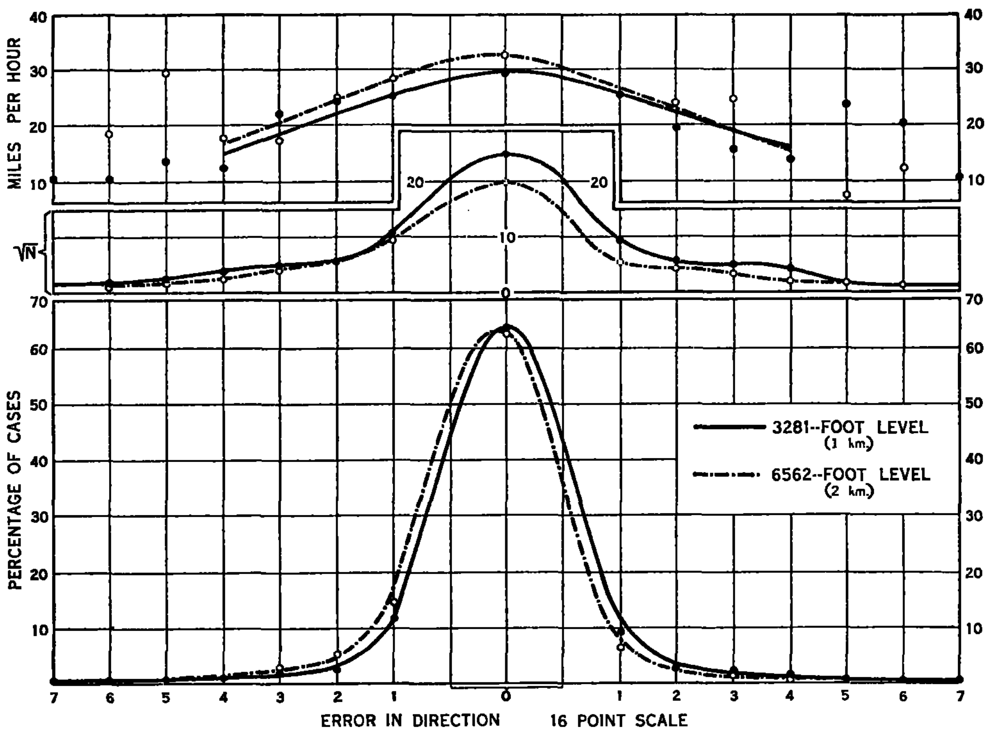

FIG. 6.—Upper section: Mean wind velocity corresponding to the several classes of error in estimating free-air wind direction. Middle section: The square root of the number of observations upon which the upper curves are based. Lower section: Curves of percentage frequency of occurrence of errors of different magnitudes in estimating free-air wind directions.

It has been noted in this figure that the curves for the two levels are slightly displaced, the upper curve lying to the right of the lower. The reason for this will not be investigated, owing to the minor practical importance of the point. It is suspected that it is associated with the effect of the eastward motion of translation of pressure systems introducing a component into the motion of air within the system.

It is more significant that the curve representing the accuracy of estimation at the upper level is almost identical with that for the lower. This shows that, in spite of the lower degree of accuracy indicated in the pressure computations for the upper level, compared with those for the lower, the accuracy of estimated wind direction at the upper level is of quite as high degree as that at the lower. This is a highly important feature of this diagram.

Figure 7 shows in the heavily-drawn upper curve the percentage of cases in which the error was a given number of points or less, the number of points being designated on the axis of abscissae. In this diagram, as in figure 4, no distinction is made between errors to right or left. Nor are the levels separated, for it was found that the percentage of accuracy for the two levels was so nearly identical in each class that the curve representing the mean of the two is wholly adequate. It is seen that 63 per cent of the estimates were correct and that 91 per cent were within two points of error. The two curves

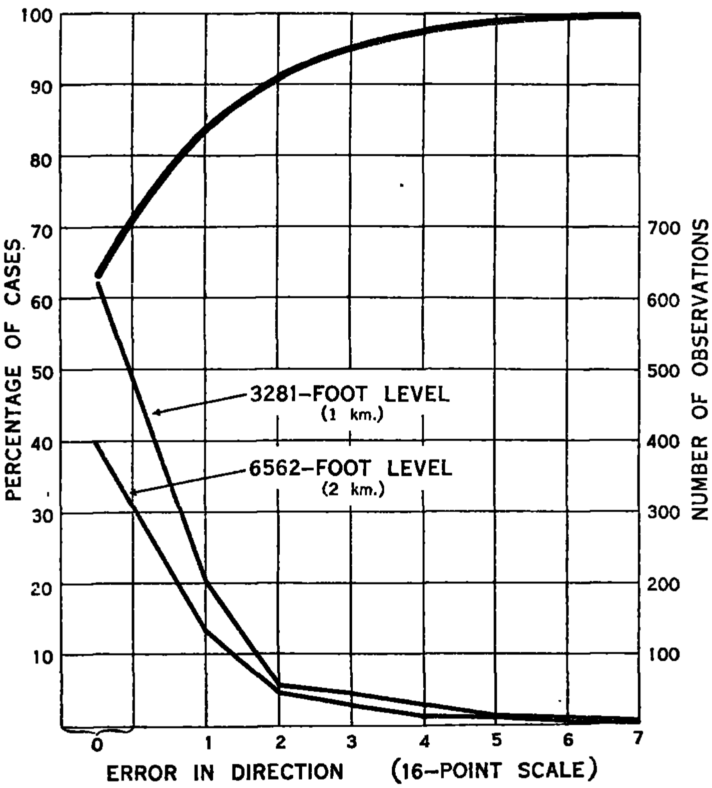

FIG. 7.—Upper curve shows the percentage of errors of estimated free-air wind direction of given magnitudes or smaller. Lower curves give the number of observations for the two levels upon which the upper curve is based.

in the lower part of the figure show the number of observations in the several classes as indicated on the scale of ordinates at the right. For the lower level a total of 984 comparisons was made; for the upper level the number was 637.

THE EFFECT OF PRESSURE ERRORS ON THE MAPS.

The exposure of thermometers and its effect upon the free-air maps.—One of the important points made in previous papers on this subject concerned the inconsequential effect upon the horizontal pressure gradient in the free air of temperature errors, provided errors of similar magnitude were made at adjacent stations. This argument is intrinsically sound. Nevertheless, it has been found that the influence most active in preventing similar errors at adjacent stations is not the factor applied to the surface temperature to obtain the mean temperature of the air column, but the surface temperature itself, owing to the non-uniform exposure of thermometers. Thus, on mornings following still, clear nights, or at the times of a cold wave, the thermometers at city stations roundabout aerological stations may register several degrees higher than the latter. Under such conditions, the resulting reductions are more nearly correct at city stations than at kite stations, and irregularities in the isobars occur in the vicinity of the aerological stations.

An interesting demonstration of this difference in current temperatures between near-by stations when the thermometers are differently exposed is to be found between Drexel and Omaha, Nebr.; and between Groesbeck and Palestine, Tex. Records for the month of January, 1923, only have been examined, but they show clearly what a more exhaustive investigation probably would disclose to a nicety, namely, that there is an approximately linear inverse relation between the velocity of the wind at the aerological station and the current temperature difference between the two stations. In other words, high wind velocity is associated with small difference of temperature (because of turbulence) and conversely. No variation with wind direction was so apparent. Therefore, when the kite station values are in harmony with those of surrounding stations, it is found that there is higher wind velocity and less difference between the current surface temperatures. Thus, at times of largest errors, the city exposures are better for the purpose than are those at aerological stations.

At the outset, it may seem paradoxical that the aerological stations from which the original data for the investigation were derived should be found less suitable than city stations. But the reason is apparent, namely, that the city station temperatures on these particular occasions are in better agreement with average conditions at aerological stations than are the temperatures at aerological stations themselves. Moreover, if all the stations where these free-air reductions are made were aerological stations, the map would probably not be so seriously affected. But since they are not, it is necessary for the minority to yield.

How may the situation be remedied?—The following schemes suggest themselves in consideration of means to prevent the occurrence of large residuals when comparisons are made with observed pressures, and also to produce more accurate maps:

(1) To correct the aerological station temperature tables by amounts which would bring them into accord with surrounding stations; or,

(2) To eliminate the aerological stations from the network, using only regular Weather Bureau stations.

There is hardly justification for the first plan in such tests as this, based upon a single season of comparisons. Next winter may be singularly free from such inversions as were productive of large negative errors during the present season. The significant point is that, in general, the temperature differences between city and country exposures were small except when large pressure discrepancies occurred at the free-air levels. Therefore, it seems that the second suggestion, i. e., the elimination of aerological stations from the network, would yield the more satisfactory maps.

The effect of occasional large errors on the map.—Granting occasional large computational errors, what will be the effect on the map? This question is not raised to condone the errors, for the effort and desire are for the elimination of error so far as possible, but to examine qualitatively the results of the comparisons.

A scrutiny of the various dates when comparisons of pressure were made indicates that December 22, 1922, was the occasion when several of the largest errors of which we have knowledge occurred simultaneously at the aerological stations. A map of this date must be a fair example of just how seriously the isobaric distribution is affected. Figure 8 shows for sea-level, and for the

DECEMBER 22, 1922.
8 a.m., 75th Meridian Time.

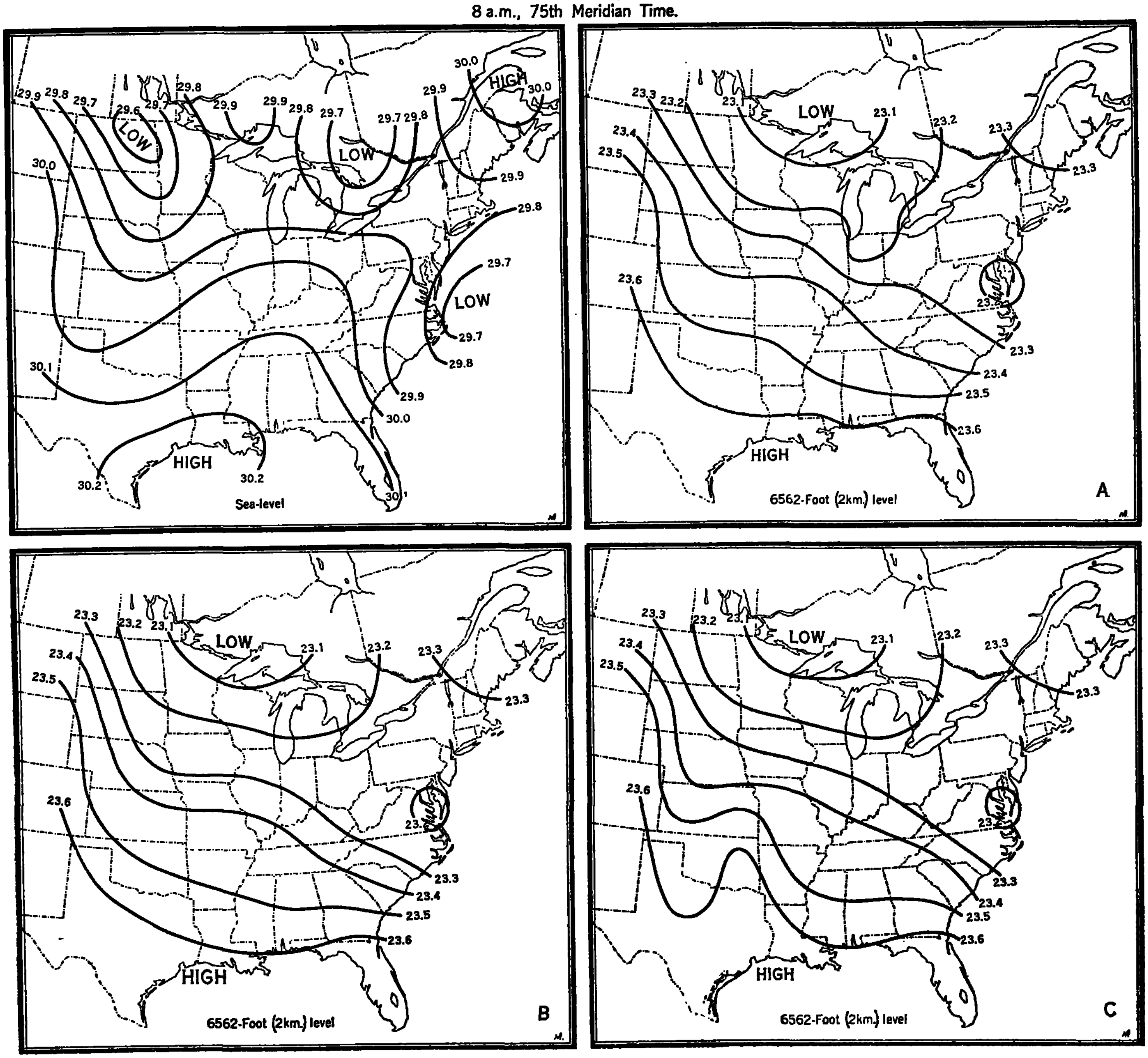

FIG. 8.—Sea-level and 6,562-foot-level maps for December 22, 1922, 8 a. m., 75th meridian time. For differences in drawing maps A, B, and C, see discussion in text.

6,562-foot level (maps A, B, and C) the barometric charts for the date in question. Map A is drawn from the *complete list of stations as reported by post card.* Map B is based upon the *regular Weather Bureau stations only,* aerological stations being eliminated. Map C results from using the pressures *measured by kites,* together with those computed at regular Weather Bureau stations. In other words, the data submitted on post cards from city stations have been used in each of the maps; but the aerological stations have been varied, using first the computed pressure; second, no values at all; and, third, the observed values.

In map A there is a questionable-looking southward loop of the isobar about Royal Center, Ind. In map B the loop is eliminated, and practically no change results elsewhere. In map C the pressure at Broken Arrow, Okla., and Groesbeck, Tex., are increased so as to produce a northward projection of high pressure from the Gulf region. The Royal Center loop is not apparent.

In general, these maps do not disagree as to the major features. In limited regions, such as central Texas, it is clear that under such conditions the wind estimate from either map A or B would be somewhat in error, assuming the gradient-wind conditions obtained. Nevertheless, when we consider that the difference between the sea-level map and those for the upper level is so striking, and that the differences between individuals A, B, and C are so small, there is little doubt that the important and significant features of the true isobaric distribution at the upper level are depicted. The anomalous loops, such as that about Royal Center, Ind., on map A, when based on a single station, are easily recognized as erroneous and allowance can be made. But this should not be necessary, and it is contended that if the type of map exemplified by map B were used—that is, if the aerological stations were not used but near-by regular stations substituted, so far as possible—the resulting maps would be highly accurate and dependable so far as free-air barometric gradients are concerned. This procedure is suggested in further activities of this character.

CONCLUSION.

An effort has been made in this paper to set forth clearly and impartially the results of a statistical examination of a three months' series of free-air pressure maps. It was first shown that a very large percentage of comparisons between observed and computed pressures lay within small error limits, better results being obtained at the 3,281-foot than at the 6,562-foot level. With all the uncertainties of the gradient-wind assumptions and the short-period vagaries of the observed wind, an extremely high percentage of agreement (practically the same at both levels) was found between the wind estimated from the isobaric charts of the free air, and that observed by pilot balloons. The average velocity of the wind falls off appreciably with the larger errors of estimated wind direction, so that, usually, when a serious error of estimation is made, the velocity of the wind is so small as to render the wind direction inconsequential. This is especially significant in estimating winds for aircraft. On the poorest day available the difference between maps drawn with and without the aerological stations and also with the observed pressures at aerological stations was so small that little-differing conclusions might be drawn from each.

It was stated in the beginning that if the maps could be proved to be accurate their scientific value would stand unchallenged. If this discussion of the accuracy of the maps has been convincing, it will be seen that there is here provided a means of knowing, quite independently of current aerological observation, the current wind conditions in the free air over large areas of the country, whether the weather be clear or cloudy. At present, the pilot-balloon stations telegraph the free-air winds as soon as possible for the use of the forecaster. Often such observations are impossible because of cloudiness, rain, snow, or fog. When used in conjunction with the aerological reports, these charts should constitute a most valuable means of weaving the various reports into a continuous pressure system, a speculative and uncertain matter at present. The advantage of such maps for aviation is obvious.

It would be quite impossible, even if it were within the scope of this paper to discuss the point, to indicate the precise manner in which these charts should be utilized in general forecasting. That must be determined by actual trial; and by actual trial is meant day-to-day telegraphing of free-air pressures in order that they may be available to the forecaster for comparison with other data while the current weather situation is fresh in mind. It is common knowledge that the growth of aviation implies increasing demands upon the Weather Bureau. Is it not essential, therefore, that every means be employed to acquire experience and familiarity with actual physical processes in the free air, while the science of aeronautical meteorology is yet in its infancy? The day will come when this knowledge *will* be required, and since it can only be acquired by experience it is the exercise of foresight to make a practical trial of the maps. This trial should continue for at least a year, and, during that time, all possible constructive criticism should be brought to bear upon the maps.

Acknowledgments.—The large amount of observational data used for comparison purposes in this paper could not have been assembled without the enthusiastic assistance of Mr. L. T. Samuels, Mr. W. C. Haines, and their associates in the Aerological Division of the Weather Bureau. They manifested considerable personal interest in the results and contributed many helpful suggestions; they were particularly prompt, also, in supplying data and in ferreting out the facts concerning suspected errors. For this cooperation the author records his earnest thanks.

COX ON THERMAL BELTS AND FRUIT GROWING IN NORTH CAROLINA.[1]

By ALFRED J. HENRY.

[Weather Bureau, Washington, D. C., May 7, 1923.]

NOTE.—According to custom an abstract and review of MONTHLY WEATHER REVIEW SUPPLEMENT No. 19 is presented below. These SUPPLEMENTS contain the results of the more comprehensive studies made by Weather Bureau officials or others. They appear at irregular intervals and are generally too voluminous to appear in the REVIEW proper.

As a result of economies in printing that have recently become effective the edition of the SUPPLEMENTS is not large enough to supply the regular REVIEW readers. The SUPPLEMENT will be sent free, however, to those who may have a practical interest in the subject investigated, but only upon application, and so long as the bureaus' supply lasts. After that is exhausted applicants will be referred to the Superintendent of Documents, Washington, D. C. The price of this supplement is 50 cents.—EDITOR.

The phenomenon of the stratification of the air temperature over valleys and the inclosing slopes was brought to the attention of scientific men of the United States by Silas McDowell, of Franklin, Macon County, N. C., more than 60 years ago. McDowell was a farmer with leanings toward botany and geology, who spent his entire life in the mountain region of western North Carolina. His first published account of thermal belts or verdant zones, as he called them, appeared in the report of the Commissioner of Patents for 1861, and the substance of that report was later presented to the Philosophical Society of Washington (D. C.), by Dr. J. J. Chickering. The late Prof. John LeConte, of Berkeley, Calif., writing in *Science*,[2] confirmed McDowell's observations and added the statement that the ground in the thermal belts freezes in winter, a fact that might not be inferred from McDowell's description.

The explanation of the phenomena offered by McDowell would hardly be accepted at this time, but nevertheless

[1] Cox, H. J.: Thermal belts and fruit growing in North Carolina; with an appendix: Thermal belts from the horticultural viewpoint, by W. N. Hutt, former State horticulturist, MONTHLY WEATHER REVIEW SUPPLEMENT NO. 19.

[2] 1883, vol. 1, p. 278.